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Investigation of Hydrodynamic Pressure in High-speed Precision Grinding

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Abstract

The conventional method of delivering grinding fluid that floods delivery with high supply fluid pressure and nozzle fluid rare to achieve high performance grinding. However, the hydrodynamic fluid pressure can be generated ahead of the contact zone due to the wedge effect between the wheel's peripheral surface and the work surface. Indeed, this reduces the depth of cutting and increases grinding wheel spindle deformation and overall grinding resistance, thereby affecting machining accuracy. In this paper, a theoretical hydrodynamic pressure modeling is presented for the flow of coolant through the grinding zone during high-speed precision grinding. The simulated results show that the hydrodynamic pressure was proportional to the velocity of the grinding wheel and inverse proportional to the minimum gap between the wheel and the workpiece. Furthermore, the hydrodynamic pressure peak value was only generated in the minimum clearance region where a higher fluid pressure gradient was observed. It can also be deduced that the hydrodynamic pressure distribution was uniform in the direction of the width of the wheel. However, due to side leakage, the edge of the wheel was an exception to this rule.

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Keywords: High-speed precision grinding; Hydrodynamic pressure; Boundary layer; Coolant

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Nomenclature

P	hydrodynamic pressure in the grinding zone (Pa)
h	the nominal oil film thickness (m)
u_e	entrainment speed(m/s)
η	lubricant viscosity (Pa.s)
v_s	peripheral speed of grinding wheel(m/s)
v_w	feed rate of workpiece(m/s)
x, y	coordinate variables of the entrainment direction and the direction perpendicular to the entrainment direction (m)
h_0	the minimal gap between grinding wheel and workpiece (m)
R_x	grinding wheel's radius (m)
R_y	the radius of rounded angle in grinding wheel end (m)
L	the width of the grinding wheel (m)
f_Δ	sign function

1. Introduction

Grinding processes are techniques employed widely as a finishing. However, during the grinding process, high temperatures may lead to thermal damage to the work surface, inducing micro-cracks and tensile residual stresses at the ground surfaces. Such cracks and stresses deteriorate the surface quality and integrity of the ground surface. This damage can be reduced by the application of flood delivering coolant fluid that removes the heat created and lubricates the two surfaces in order to decrease the amount of friction. A number of investigations have focused on ensuring a large volumetric flow rate into the grinding zone in order to overcome the boundary layer of air. However, due to the wedge effect between the wheel and the work surface, a considerable amount of hydrodynamic pressure is generated during the grinding process. Moreover, conventional methods of flood delivering coolant fluid via a shoe nozzle tangential to the wheel are not believed to fully penetrate this boundary layer of air. Consequently, the majority of grinding fluid is deflected away from the grinding zone [1-6]. Therefore, the flood delivery of a grinding fluid not only that increase hydrodynamic lift force, result in reduce the depth of cutting, and increase grinding wheel spindle deformation, but also that increase high disposal costs in production. The goal of this project is to model the hydrodynamic fluid pressure during high-speed precision grinding both theoretically and experimentally so as to find the quantitative relationship between the hydrodynamic pressure and grinding conditions.

2. Theoretical modeling

The problem to be investigated is presented schematically in Fig. 1, which represents a typical surface precision grinding in which the wheel depth of cut is very small and can be neglected. It is assumed that the entrance is well flooded with fluid. It should be noted that the method by which the fluid is delivered is not considered. The workpiece speed is neglected, as it is typically much smaller than the wheel speed. It is assumed that both the wheel and the workpiece are smooth and that surface roughness is almost negligible because the average film thickness is larger than 1.5 times the root-mean square roughness. The coolant fluid is Newtonian, uncompressible steady flow, constant viscosity, no slip on the surface of wheel and workpiece. Constant pressure along the film thickness direction, negligibly small inertia force compared with viscous force because of the small gap near the grinding contact region. The flow field and the developed hydrodynamic pressure, or p (x, y), need to be determined as a function of the wheel speed, the minimum film thickness, and the physical properties of the fluid. The problem is investigated using a continuous equation and Navier-Stokes equations. The Navier-Stokes equations are simplified to the following equations using the above assumptions:

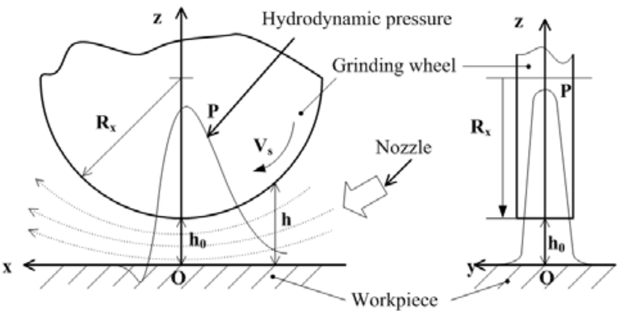

Fig.1 The sketch of hydrodynamic fluid pressure on smooth surface

$$\frac{\partial}{\partial x}\left(\frac{h^3}{12\eta}\frac{\partial p}{\partial x}-\frac{1}{2}v_s h\right)+\frac{\partial}{\partial y}\left(\frac{h^3}{12\eta}\frac{\partial p}{\partial y}\right)=0 \tag{1}$$

Also, $u_e = \frac{1}{2}(v_s + v_w)$, because $v_w << v_s$, v_w can be omitted, i.e. $u_e = \frac{1}{2}v_s$.

Then Formula (1) is arranged to become:

$$\frac{\partial}{\partial x}\left(\frac{h^3}{12\eta}\frac{\partial p}{\partial x}-u_e h\right)+\frac{\partial}{\partial y}\left(\frac{h^3}{12\eta}\frac{\partial p}{\partial y}\right)=0 \tag{2}$$

The film thickness equation of the wedge-like contact zone is:

$$h(x,y)=h_0+\frac{x^2}{2R_x}+\frac{(y-L/2)^2}{2R_y}f_\Delta \tag{3}$$

when y > $L/2$, $f_\Delta = 1$, and when y ≤ $L/2$, $f_\Delta = 0$.

The boundary conditions in Equation (2):

$$\begin{cases} p(x_{in}, y) = p(x_{out}, y) = p(x, y_{out}) = 0 \\ \left.\dfrac{\partial p}{\partial y}\right|_{y=0} = 0 \\ p(x, y) \geq 0 \quad (x_{in} < x < x_{out}, 0 \leq y < y_{out}) \end{cases} \tag{4}$$

In the formula, the index "in" and "out" represent the boundaries of the computational field, the symmetry axis satisfies the conditions of $\left.\dfrac{\partial p}{\partial y}\right|_{y=0} = 0$.

3. Analysis of Numerical Results

3.1. Hydrodynamic fluid pressure vector distribution

From the hydrodynamic fluid pressure vector distribution shown in Fig. 2, it can be seen that a sufficient amount of coolant can wipe off the work surface longitudinally, as well as slip transversely at the edge due to side leakage. The grinding fluid is deflected away from the grinding zone and can be discovered at the entrance.

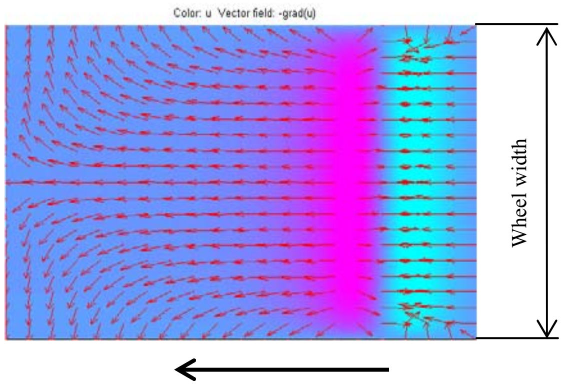

Fig.2 Hydrodynamic pressure vector profile

3.2. Hydrodynamic pressure distribution

Figs. 3 and 4 show the hydrodynamic pressure distribution developed ahead of the wedge-like contact zone between the wheel and the work surface. As a result of calculating Eq. (2), we are able to show the pressure distribution both two-dimensionally and three-dimensionally. There is high pressure value and the rapid pressure gradient occurs near the region where the gap between the wheel and the work surface is minimal. The smaller the gap distance is, the higher the pressure gradient and the peak value pressure attained. The magnitude of the pressure is proportional to the surface velocity of the wheel, as shown in Fig. 4. In the width direction of grinding wheel, the hydrodynamic pressure was the same except that side leakage existed at width-direction edges of grinding wheel.

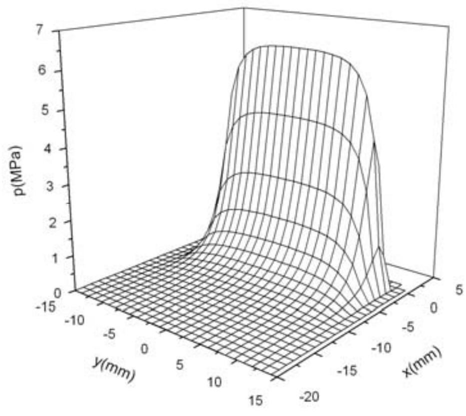

Fig. 3 hydrodynamic pressure 3D distribution

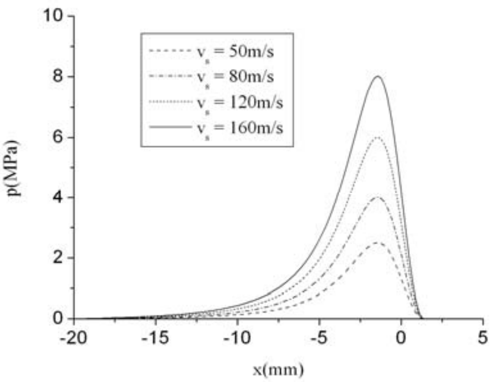

Fig. 4 hydrodynamic pressure change under different wheel velocity

4. Conclusions

The models for determining the hydrodynamic fluid pressure of the contact zone between the grinding wheel and the work surface on flood delivery grinding were presented based on Navier-Stokes equations and continuous equations. The simulated results show that the hydrodynamic pressure was proportional to the velocity of the grinding wheel and inverse proportional to the minimum gap between the wheel and the workpiece. Furthermore, the hydrodynamic pressure peak value was only generated in the minimum clearance region where a higher fluid pressure gradient was observed. It can also be deduced that the hydrodynamic pressure distribution was uniform in the direction of the width of the wheel. However, due to side leakage, the edge of the wheel was an exception to this rule.

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References

[1] Gviniashvili V, Webster J, Rowe B. Fluid Flow and Pressure in the Grinding Wheel-Workpiece Interface. Transactions of the ASME 2005; 127:198-205.

[2] Li C H, Cai G Q, Xiu S C. Hydrodynamic Pressure Modeling and Verification of Contact Zone on Abrasive Jet Finishing with Grinding Wheel as Restraint. Acta Armamentarii 2007; 28:202-205.

[3] Li C H, Hou Y L, Ding Y C, Cai G Q. Feasibility investigations on compound process: a novel fabrication method for finishing with grinding wheel as restraint. Int. J. of Computational Materials Science and Surface Engineering 2011. 4(1):55 - 68.

[4] Lee Sun-Kyu, Miyamoto Yuji, Kuriyagawa Tsunemoto, Syoji Katsuo. Effects of minimizing hydrodynamic pressure in ultra-precision mirror grinding. International Journal of Machine Tools & Manufacture 2004; 44:1031–1036.